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PLASMA-PROPELLANT INTERACTION STUDIES

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SUMMARY

The overall objective is to gain insights about of the various chemical and physical processes that occur during ignition of a solid propellant by a high-pressure and high-temperature plasma. The plasma is formed within a hydrocarbon capillary by an electrical discharge process. The plasma emerges into stagnant air as an underexpanded supersonic jet. Two experimental approaches are applied. A triple-quadrupole mass spectrometer is employed to examine species from the plasma and the pyrolysis products from the propellant generated by interactions with the plasma. A fast-response heat flux gauge has been designed and utilized to determine the transient variation of the radiant heat flux, with specific emphasis on the UV to near-visible components. The results show that the use of different trigger-wire and capillary materials yields significant differences in the ignition and combustion of JA2 and transparent JA2, as well as in the radiative heat flux levels.

TECHNICAL DISCUSSION

Plasma-driven Ignition and Combustion of JA2 and Transparent JA2

The focus of this part of the investigation to examine the effects of initiating-wire and capillary materials on the ignition and combustion of selected propellants. Experiments were conducted in a small chamber with a volume of 8.2cm^3; both JA2 and transparent JA2 (t-JA2) were studied. JA2 is a double-base propellant, containing nitrocellulose, nitroglycerine, diethyleneglycol dinitrate, akardit, and carbon black; the t-JA2 contains no carbon black. An 8mm×8mm test sample, weighing approximately 260mg, was cut from a thin (2.5mm) sheet of propellant and placed on the sample holder near the plasma exit. The distance from the exit to the sample was 3mm for all tests. The charging voltage was set at 4kV, corresponding to a peak power output about 19-20 kW. Three wire materials, aluminum (Al), copper (Cu), and nickel (Ni), were tested along with three capillary materials: polyethylene (PE), Lexan (LE) and Teflon (TE). In addition, the mass of wire was also varied. The capillary size was 4mm (i.d.) by 26mm (length) in all tests.

Figure 1 presents the traces of voltage versus time for the three different wire materials. The discharge voltage shows the transition from a trigger-wire sustained plasma to a capillary-sustained plasma, and thus it is a better parameter than the discharge current to monitor the discharge process. As shown in Fig. 1, the traces of

voltage indicate a clear sequence (in tests with both JA2 and t-JA2) in the transition with nickel being earliest followed by aluminum and then by copper. This trend was confirmed by three tests for each wire material. The difference in wire-to-capillary transition is expected to have an effect on the ignition and combustion of the propellants.

Figure 2 shows the combustion pressures for the three wires and for both JA2 and t-JA2; the measured capillary ablation mass is listed in the legend of the figure. The highest combustion pressure is obtained with the nickel wire in the case of JA2, while the aluminum wire results in the highest combustion pressure for t-JA2. Examination of the capillary ablation mass shows that combustion of these propellants is more strongly related to the ablation mass than the wire-to-capillary transition times. As seen from the figures, greater ablation mass tends to result in faster burning and higher pressure. It should be noted that the results showed variation from test to test and thus further work is needed to verify the effects demonstrated in current work. In addition, testing with the different capillary materials has begun but the test-to-test variation is not yet acceptable.

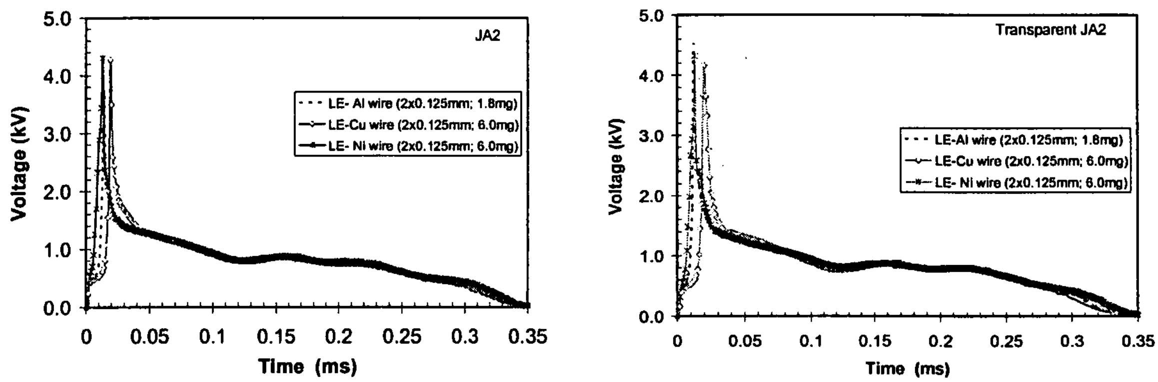

Fig. 1 Discharge voltages for different initiating wires.

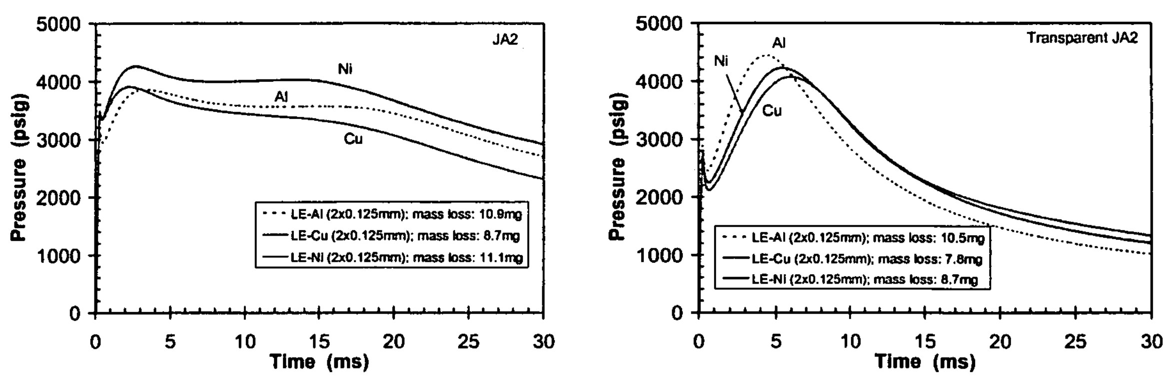

Fig. 2 Comparison of the effect of different wire materials on the combustion of JA2 and transparent JA2.

Radiant Heat Flux Measurements

Previous reports described the design and manufacturing of a thin-film Pt gage for estimating the transient radiant heat flux from ETC plasma. Initial results from the open-air experiments were also reported. These experiments were conducted with a PE capillary and Cu wire with charging voltages of 2.5 (0.60kJ) and 3.0kV (0.87kJ). The ETC plasma, generated by exploding the Cu wire and sustained by ablation of the PE

capillary, emerged from a Cu nozzle to impinge on a stagnation plate equipped with an array of heat flux gages. Gages were manufactured by sputtering 80nm Pt over 50μm polyimide substrate, followed by adequate heat treatment. Nozzle exit to stagnation plate distance was maintained 50 and 75mm.

Based on the initial success of the experimental procedure, a material dependence study of ETC plasma was conducted. During this investigation nine different capillary-trigger wire combinations are studied, using PE, LE and TE capillaries with Cu, Al and Ni wires. Charging voltage was maintained 2.5kV with nozzle to stagnation plate distance of 50mm. The results show that appreciable differences are present among the capillary and wire combinations, with a LE capillary and copper wire yielding the largest radiant energy deposition in the substrate. Figure 3 shows the transient temperature, radiant heat flux and stagnation pressure variation on the stagnation plate at the exit port centerline for the PE capillary with Al, and Ni trigger wires. The use of the Al wire, with its smoothly varying current, produces the largest peak radiant heat flux. The radiant heating begins around 40 μs into the event, indicating that plasma emergence is rapid. Peak radiant heat fluxes are obtained prior to arrival of the precursor shock, and they generally coincide with the peak of the current flow. Cases with Ni wires suggest a slight change or increase (second rise) when peak stagnation pressures are achieved. It is not clear if this effect is a chemically induced effect caused by reactions between Ni and surrounding air, or differences in the radiative properties between Al, and Ni. The secondary increased radiative heat flux for Ni is not caused by the arrival of particles (from wire or nozzle), since the quartz window remains quite clear after one firing. However, inspection of atomic line data reveals that neutral and singly ionized Al has relatively few lines produced by electronic transitions covering wavelengths from 200 nm to approximately 700 nm, whereas Ni has a much larger number of lines. Any further assessment regarding spectral emission characteristics requires additional experiments. The compressible flow produces strong pressure oscillations that appear quite insensitive to the type of trigger wire material used. The large peak radiant heat flux from the case with Al wire may only partially contribute to a reduced plasma temperature and thus produces the lowest peak pressure; the reduction is much more likely due to a lower plasma density.

While the above studies clearly indicated the effectiveness of the heat flux gages, it was also observed that the gages were destroyed at higher energy levels such as, 4kV-50mm combination. An improved gage design, comprising a sapphire substrate instead of polyimide, is utilized to circumvent this issue. While a higher thermal conductivity and heat capacity of sapphire yielded in successful measurement of high heat fluxes, the same properties produce two-dimensional heat conduction effects within the substrate, which is generally neglected in a typical one-dimensional (1-D) inverse data reduction scheme. A two-dimensional (2-D) data reduction technique is, therefore, devised. Figure 4 shows the performance of 1- and 2-D data reduction schemes for 2.5kV (0.6kJ) and 7.5kV (5.4kJ) plasmas. PE capillary and Cu wire are used in both cases with a nozzle exit to stagnation plate distance of 50mm. While polyimide substrate was used for the 0.6kJ plasma, higher energy level measurements utilized a sapphire substrate. The results clearly revealed significant departure from 1-D heat conduction during higher energy level.

Based on successful redesigning of the heat flux gage as well as the data reduction scheme, a parametric study on radiative transport from ETC plasma has been

accomplished and will be reported soon. Efforts are underway to quantify the spectral variation of the radiative heat fluxes using UV-Visible spectroscopy. Further studies to identify the effects of radiant fluxes on the propellant have also been planned.

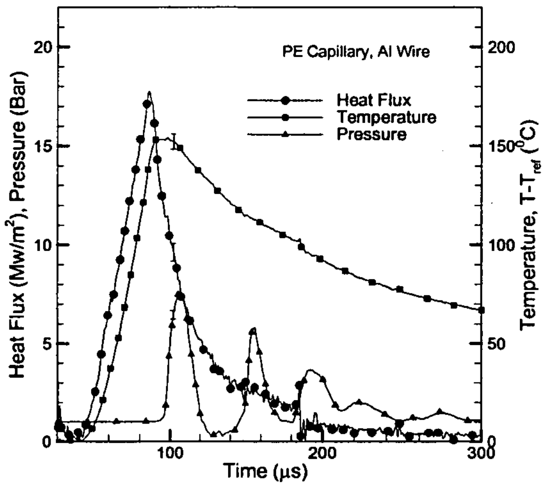

Fig. 3 Transient variation of pressure, temperature and radiant heat flux at the stagnation location for PE capillary with Cu and Ni wires for a charging voltage of 2.5 kV and a nozzle exit to stagnation plate distance of 50 mm.

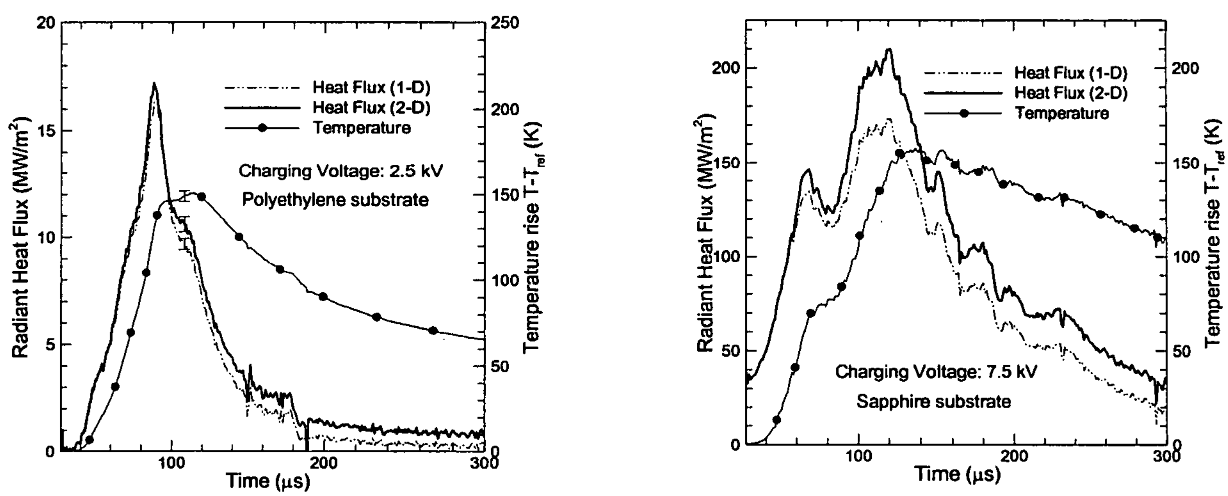

Fig. 4 Performance of 1- and 2-D data reduction approach for radiant heat fluxes using 2.5 and 7.5kV charging voltages with a nozzle exit to stagnation plate distance of 50mm.